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Human Factors in Intelligence, Surveillance, and Reconnaissance: Gaps for Soldiers and Technology Recommendations

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ARL-RP-0490 **July 2014**

A reprint from the *2013 IEEE Military Communications Conference*,
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14. ABSTRACT

We investigate the gaps for Soldiers in information collection and resource management for Intelligence, Surveillance, and Reconnaissance (ISR). ISR comprises the intelligence functions supporting military operations; we concentrate on ISR for physical sensors (air and ground platforms). To identify gaps, we use approaches from Human Factors (interactions between humans and technical systems to optimize human and system performance) at the level of Soldier functions/activities in ISR. Key gaps (e.g., the loud auditory signatures of some air assets, unofficial ISR requests, and unintended battlefield effects) are identified. These gaps illustrate that ISR is not purely a technical problem. Instead, interactions between technical systems, humans, and the environment result in unpredictability and adaptability in using technical systems. To mitigate these gaps, we provide technology recommendations.

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***Abstract*—We investigate the gaps for Soldiers in information collection and resource management for Intelligence, Surveillance, and Reconnaissance (ISR). ISR comprises the intelligence functions supporting military operations; we concentrate on ISR for physical sensors (air and ground platforms). To identify gaps, we use approaches from Human Factors (interactions between humans and technical systems to optimize human and system performance) at the level of Soldier functions/activities in ISR. Key gaps (e.g., the loud auditory signatures of some air assets, unofficial ISR requests, and unintended battlefield effects) are identified. These gaps illustrate that ISR is not purely a technical problem. Instead, interactions between technical systems, humans, and the environment result in unpredictability and adaptability in using technical systems. To mitigate these gaps, we provide technology recommendations.**

Keywords*—intelligence, surveillance, and reconnaissance; ISR; human factors; human-systems integration; cognitive systems engineering; intelligence

I. Introduction

Intelligence, surveillance, and reconnaissance (ISR) is the "…'hub' of 21st Century (Military) Operations" [1]. ISR comprises the integrated intelligence functions supporting military operations [2]. The U.S. Army conceptualizes functions of the intelligence cycle as information: Collection, Processing, Exploitation, and Dissemination (CPED) [3]; the U.K. military also conceptualizes an intelligence cycle similar to CPED. There are two distinct sources for information collection [4]:

1. *Soft sources*: Information from humans (e.g., human terrain mapping, an interview with a confidential informant, and social media).
2. *Hard sources*: Information from physical sensors (e.g., visible imagery captured by an unmanned aerial vehicle).

This paper primarily focuses on hard sources of information.

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The purpose of this research was to examine information collection and resource management of ISR assets (typically aerial assets but also ground assets) and the battlefield effects of ISR based on Soldier goals, constraints, and priorities. In addition, we provide technology recommendations for many of the identified gaps. Gaps were identified based on semi-structured interviews with subject matter experts (U.S. Army Soldiers with ISR experience during deployment) using approaches from Human Factors. Human Factors[1] is defined as understanding the human interactions with systems (e.g., technical systems, communication with other humans) to optimize both human performance and overall system performance [7], [8]. Human Factors is an integral part of the successful development and implementation of technology (i.e., supporting and enhancing human cognitive performance) because of the [8], [9]:

1. Fundamental limits of human performance.
2. Large number of ways humans can interact or use (technical and other) systems in dynamic operational environments, neither of which may be anticipated without an understanding of goals, activities, and tasks.

ISR is not just a technical problem; humans must make decisions about information collection and resource management. Thus, ISR involves social, natural, and technical systems. Social and natural systems tend to be less predictable, but more adaptable, than engineered (technical) systems [10]. The different systems in ISR are:

1. *Social and natural systems*: Individual humans and groups (military, civilians, and insurgents).
2. *Natural systems*: Environmental characteristics, such as the weather, terrain, and time of day.
3. *Technical systems*: Sensors and sensor platforms, communication devices and networks, and software

[1]We use the general definition of Human Factors to encompass the wide variety of other highly related disciplines or terms. Popular examples include Cognitive (Systems) Engineering, Human-Centered Computing, and Human-Systems Integration [5]. Different areas do have nuanced distinctions, but, in our opinion, they can be conceptualized as different levels of analysis for the same overarching question or problem [6]. In Europe, "Ergonomics" is commonly used in place of "Human Factors."

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systems for collecting information and managing resources.

Because ISR includes more than just technical systems, it has a large problem space. Gaps for Soldiers may result from multiple systems and their interactions. Consequently, not all gaps can be identified from a technical approach. An understanding of Soldier activities and goals is needed to determine the gaps for Soldiers in the ISR work domain.

In Section II, we cover past ISR work, which is mainly technology focused or an assessment from a military command perspective. In Section III, we discuss the study methodology, subject matter experts, and the procedure, followed by the gaps. In Section IV, to meet the identified gaps, we provide recommendations for developing and implementing technology. In Section V, we conclude the paper and discuss limitations and future directions.

II. Past Work

Past work in ISR is mainly technology focused or an assessment from a military command perspective. For long-term ISR technology, several roadmaps provide research and development plans for better sensors, improved sensor platforms, and new physical network capabilities [11-14]. General near-term technology work seeks to address gaps in the management, processing, and fusion of heterogeneous (i.e., soft and hard) information to aid human decision-making [15]. Using a technical system optimization approach, multiple capability gaps have been conceptually identified [16]; these gaps include the need for a common operating picture for assets, system interoperability, a system to determine asset suitability for collection requirements, and decision aids [16].

Specific technology efforts for ISR concentrate on different computing and network architectures (e.g., scalability, security, and bandwidth) to exploit the vast and growing amounts of data [16], [17]. There is also a broad research program on techniques for soft and hard information fusion [18]. The U.S. and U.K. International Technology Alliance in Network & Information Sciences is developing technology for coalition ISR allocation using controlled natural language [19], such as the Sensor Assignments to Mission (SAM) system [20], [21]. Last, comprehensive evaluations of tactical and operational gaps in ISR provide a military command and doctrinal perspective [22], [23].

III. Human Factors: ISR Gaps

In this section, we discuss the study methodology, subject matter experts, and the procedure, followed by the gaps. To provide structure to the interview questions, we apply elements from two functional/goal-oriented Human Factors approaches [24-26]. The general aim was to understand, "Why is a user performing an activity, task, action, or operation in the first place?" [24, pp. 15]; this approach is Activity-Centered Design [25]. A related approach, Work Domain Analysis, was also used to determine Soldier functions, goals, constraints, and priorities [26]. These approaches provided the overarching structure for interviews (see Table II).

A. Subject Matter Experts

Fourteen U.S. Army Soldiers with ISR experience were interviewed. All Soldiers had deployed experience with ISR ranging from management, collection, and analysis duties in a Tactical Operations Center to first-hand tactical experience with tactical use of ISR and the direct effects of ISR on military operations. Subject matter experts consisted of 13 males and 1 female (mean age = 27.1 years old, age unknown for 4 participants). Characteristics of subject matter experts are described in Table I.

TABLE I.
CHARACTERISTICS OF SUBJECT MATTER EXPERTS

Rank[a]	Military Occupational Specialty[b]	Description of Deployed Experience[c]
COL (retired)	Equivalent to 35-series	Intelligence OIC at DIV, BDE, and BN
CPT	35D	BN Intelligence OIC
CPT	35D	BDE Intelligence Collection Manager
CPT	35D	BN Intelligence OIC, Intelligence Operations Analyst
CPT	35F	BN Intelligence OIC
1LT	11A	Intelligence Advisor to Host Nation
1LT	11A	Intelligence Advisor to Host Nation
1LT	35D	BN Intelligence OIC
SSG	35F	DIV Intelligence Operations Analyst, BDE Collection Management
SSG	29E	BN Electronic Warfare
SGT	13B	Targeting, BN Blue Force Tracker
SGT	35F	BDE ISR Operations NCOIC
SGT	35F	BN Intelligence Analyst
SGT	35F	BN Intelligence OIC, Targeting, Operations Analyst

a. Rank descriptions: http://www.army.mil/symbols/armyranks.html

b. Military Occupational Specialty descriptions: www.apd.army.mil/Home/Links/PDFFiles/MOSBook.pdf

c. Any potentially identifying information has been omitted; the descriptions of operational experience are incomplete. Acronyms for military echelons (unit sizes): DIV, BDE, BN, and CO, respectively, stands for Division, Brigade, Battalion, and Company. For a description of military echelons, see http://en.wikipedia.org/wiki/Military_unit#Commands.2C_formations.2C_and_units
OIC is Officer in Charge and NCOIC is Non-Commissioned Officer in Charge.
The Intelligence OIC is also colloquially referred to as the "S2."

B. Procedure

Subject matter experts were recruited at an Umbrella Week (this is a scheduled week where units set aside times for researchers to interview Soldiers and administer surveys) and by asking other researchers and Soldiers for suggested contacts. All Soldiers were told that participation was completely voluntary, they could withdraw at any time and for any reason, and responses were non-attributional. Subject

matter experts received no compensation for their participation.

The first author conducted all interviews. Subject matter experts were told the purpose of the interview was to identify the tactical and operational gaps in ISR, based on their expertise and knowledge, with the end goal of improving the effectiveness of ISR. In addition, Soldiers were informed that their blunt, honest feedback would be appreciated. Some Soldiers (6 out of 14) completed a 15-minute ISR decision-making task before the interview. Results from this task are not discussed here. Examples of the standardized interview questions, for general Soldier functions, are shown in Table II.

TABLE II.
EXAMPLE INTERVIEW QUESTIONS

1) Requesting and Managing ISR • What were the biggest challenges? • Did you use workarounds to request and manage ISR (such as deviations from standard operating procedures)? If so, how and why?
2) For sensor capabilities, what are the things the NIIRS scale[d] does not take into account (i.e., its limitations)? For example, effects on the battlefield.
3) How and when (examples) does ISR tend to be effective in the tactical and operational environment? Ineffective?
4) Systems (mostly software) • What systems did you use to request, plan, and manage ISR and view collected information? • What capabilities would you like to see in future systems?

d. NIIRS stands for National Imagery Interpretability Rating Scale. It is an empirically validated scale for characterizing the quality and performance of imagery sensors based on human analyst's accuracy in target detection and target identification. See: http://www.fas.org/irp/imint/niirs.htm Note, NIIRS includes multispectral imagery (visible, radar, and infrared).

The example questions were always asked, but interviews were not limited to these questions. Follow-up questions were asked to obtain more detailed information and clarification. To verify understanding, every effort was made to ask open-ended as opposed to potentially leading or loaded questions. For security reasons, interview responses containing potentially sensitive information (e.g., tactics, techniques, and procedures or specific system capabilities) are either described generically or have been intentionally omitted at the discretion of the first author.

To save time and promote discussion among the Soldiers, a combination of interview formats were used:

1. Small group interviews: In groups of two, four, and four Soldiers.
2. Individual interviews with four Soldiers.

Six Soldiers (four individual and a group of two) were interviewed over the phone, the remaining were interviewed in person. The group and individual interviews lasted from 20 minutes to 2.5 hours (mean duration = 70.3 minutes).

C. Gaps

The interviews produced nine general gaps. These gaps are presented in Table III (the numbers in parentheses denote the correspondence to interview questions in Table II). Following Table III, gaps in software systems are discussed.

TABLE III.
ISR GAPS

Gap	Description	Reason(s)	Impact(s)
Barriers to coalition and echelon intelligence sharing (1, 3, 4)	Classified information (especially Top Secret) cannot, typically, be easily shared with coalition partners or lower echelons. There is an inexorable trade-off between maintaining security and sharing intelligence.	There is no automated or semi-automated system for reducing the classification level of intelligence (may take weeks or months to reduce the classification level or for declassification). Maintain security to protect sensitive information.	Information collected from assets with highly classified capabilities may not be directly shared with lower echelons. Limits intelligence sharing between coalition partners and echelons.
Loud unmanned aerial vehicles (Soldiers use the term "flying lawnmowers") (2, 3)	A few unmanned aerial vehicles have a distinct buzzing sound that is often audible from the ground.	Unmanned aerial vehicle operators are sometimes unaware of noise given the altitude, terrain, and weather. Certain platforms simply are much louder than other ones.	Unmanned aerial vehicles are audible to individuals on the ground; hence, detection of ISR can be undesirable (e.g., draws attention to Soldiers nearby) and also desirable (the air version of a ground "presence patrol").
No Common Operating Picture for ISR (1, 3, 4)	No single Mission Command System for ISR (air and ground assets). This refers to asset locations, rather than information fusion, the latter is addressed below.	Limited system interoperability (air and ground assets are on separate systems). Not all air assets are on the same system. Coalition forces often use different systems.	Asset allocation may be suboptimal because of limited awareness of location between echelons and coalition partners. Upper echelons disproportionately rely on air assets.
Individual differences in the operator performance of unmanned aerial vehicles (1, 2, 3)	Some expert operators could keep platforms in the air longer and collect higher-quality information (e.g., use sweeping circular flight paths instead of staying directly on top of an area).	Speculatively, a combination of differences in cognitive ability, training, and operational experience.	The effectiveness of ISR on the battlefield, including how long air platforms are available, the quality and relevance of collected information, and the likelihood of platform detection by the red force.
Purpose of information collection? (1, 2, 3, 4)	It is extremely rare to find useful intelligence without prior information (i.e., formalized as information requirements).	Too much information from disparate sources (information fusion problem) and lack of system interoperability. Without	Without a purpose information collection is unlikely to be pertinent and ISR is not likely to be effective.

Gap	Description	Reason(s)	Impact(s)
		collection requirements finding something important by chance is like finding a "needle in a haystack."	
Signals Intelligence (SIGINT) (1, 2, 3, 4)	SIGINT (cell phones and radio) intercepts can be incredibly informative (i.e., actionable intelligence), but not enough platforms have this capability.	SIGINT red forces frequently use cell phones to communicate. SIGINT is a relatively new capability.	Increased SIGINT is likely to increase actionable intelligence and help fill in various intelligence gaps.
Soldier knowledge of sensor and platform capabilities (2, 3)	Mixed knowledge of capabilities (NIIRS scale and other capabilities). Some Soldiers self-reported that they had expert knowledge; others indicated they should know the specific capabilities of assets, but did not.	Lack of formal training (for many non-intelligence Military Occupational Specialties). Gaps between training and conditions on the battlefield (acquiring expert knowledge may require substantial operational experience). Sensors and platforms change (e.g., updated sensor packages).	Asset allocation may be suboptimal (over and under allocation in terms of sensor and platform capabilities).
Specialized technical knowledge and skills needed to configure ground sensors (3, 4)	Few Soldiers can configure ground sensors (typically this requires a Field Service Representative).	Requires highly specialized technical knowledge (sensors have disparate, proprietary programming interfaces). No common interface (e.g., no general architecture) for configuring ground sensors.	Ground sensors may have reduced effectiveness (e.g., not configured for key alerts) or even go unused (e.g., too many false positives).
Unofficial ISR requests (Soldiers call these 'drug deals') (1, 3)	Off the books ISR requests (not put through the official chain of command).	Sometimes requests take too long to get fulfilled (e.g., must be put in two weeks in advance) or go unfulfilled with no explanation using the official process. The method for putting in requests is not necessarily standardized.	Potentially saves time and improves ISR coverage. Can greatly speed up the time it takes to get ISR (from up to two weeks down to minutes). Although rare, this method allows Soldiers to obtain ISR assets owned by echelons multiple levels above them.

ISR Software Systems

The general issue with ISR software systems was a lack of integration. Subject matter experts noted using two main software systems to manage ISR: Google Earth[2] and a North Atlantic Treaty Organization (NATO) system. Google Earth was used to perform the following functions:

1. Flight planning: Plan and share planned air ISR tracks.
2. Common Operating Picture: Real-time air ISR tracking, limited to specific air platforms and ones equipped with functioning trackers.
3. Sensor Feeds: View real-time feeds (when supported).

The NATO system was Interim Geo-Spatial Intelligence Tool (IGeoSIT) [27]. IGeoSIT was used in similar ways to Google Earth and had many of the same limitations. In addition to software, white boards, magnetic boards, and paper were commonly used to manage air asset patrol schedules (i.e., the ISR synchronization matrix) and to keep track of the location of air assets.

IV. Recommendations

To mitigate the identified gaps, we provide recommendations for developing and implementing technology. Specific recommendations are provided for some of the gaps highlighted above. In unpredictable, dynamic work domains (such as ISR), we contend that enhancing human performance requires technical systems that are adaptive, interactive, integrated (as few unique systems as possible), and transparent (see [10], [28]). Decision aids may enhance Soldier decision-making for ISR allocation and resource management, but new technical capabilities need to also be flexible (e.g., ad-hoc and unofficial ISR requests). Although we were unable to provide recommendations for all of the gaps, we hope our list will be a helpful guide for others.

A. Common Operating Picture for Air and Ground Assets

Existing systems do not provide a comprehensive Common Operating Picture. Unit location is not necessarily predictable and for ISR, is an important part of management and allocation (e.g., distance to the target or area of interest). A dynamic, integrated Common Operating Picture would increase Soldier awareness of available ISR resources and help keep "options available" as opposed to committing to an irreversible course of action. The issue of limited information on locations of ISR units between echelons and coalition partners is due to different systems, lack of interoperability, security, and possibly additional issues. Locations of ISR assets are often reported over the radio. One Soldier had an intriguing suggestion: using technology to process radio reports of unit locations to update asset location on digital maps.

[2] http://www.google.com/earth/index.html

B. Adapative Decision Aids

In the military domain, empirical research on cognitive performance with decision aids is rare. A notable exception is evidence for enhanced cognitive performance in Mission Command with specific decision aids [29]. In a similarly unpredictable and safety-critical domain, health care, the effectiveness of decision aids for clinician performance is mixed [30]. The mixed results in health care are partially attributed to mismatches between the often rigid implementation decision aids with unpredictable work processes [28]. Implementation of decision aids is a complex, multidimensional problem due to the variety of decision aids and their varying levels of automation [8].

Nevertheless, decision aids may help mitigate ISR resource management and allocation challenges. In particular, it would be useful to provide Soldiers with ISR asset recommendations based on rationale for matching sensor and corresponding platform capabilities to different allocation tasks. Furthermore, decision aids may be expanded to assist with flight planning to help novice air asset operators perform like experts and to represent sensor capabilities (e.g., imagery, SIGINT) and the auditory signatures of air assets over different terrain, weather, and other environmental conditions.

The technological approach we are pursuing for decision-aiding is the SAM system [20], [21]—an artificial intelligence (AI) system for ISR resource allocation. SAM uses a controlled natural language as a common human and machine-readable representation of knowledge, thus it is likely to have greater transparency to humans than black box AI. In addition, an interactive conversational interface for SAM is under development, allowing users to change and update ISR allocation tasks [31]. We plan to conduct behavioral research to assess and iteratively improve SAM for human cognitive performance (see [32]).

C. Security

Partial automation of security may increase the speed, quantity, and critically the quality of information sharing. One approach that we are investigating is using controlled natural language to automate sharing ISR assets between coalition partners and echelons [33]; this approach may also work for automation of information sharing policies. Soldiers reported that Palantir [3] (a software system for general intelligence analysis) has security and data-sharing policies, automating sharing of information, and intelligence products.

D. Other Gaps

Other gaps may also be addressed by ongoing technology efforts. The loud auditory signatures of air platforms may be partially mitigated by a combination of technological advances in design and acoustic modeling [34]. For example, this could be accomplished through integration of acoustic modeling to depict asset auditory signatures in flight planning software and real-time modeling during the operating of air platforms. Signal modeling could also be implemented as decision aids, recommendations to improve asset "coverage" (e.g., visible imagery, SIGINT). In addition, interoperability issues with configuration and alerts from ground sensors may be minimized with open architecture standards (e.g., Open Geospatial Consortium's Sensor Web Enablement Initiative [4] and Terra Harvest [5]). Such standards may enable integration of disparate ISR sensor feeds into a single system.

E. Integration

We strongly recommend that novel technology is integrated into an existing Mission Command System instead of creating another new system. Unless a new Mission Command System is truly a usable "system of systems," the introduction of yet another system is likely to create more problems for Soldiers than will be solved. The sheer number of different Mission Command Systems is a general and growing problem for the military. In response to the question of developing new capabilities, nearly all Soldiers called for integration with existing systems. Poor system interoperability often means the same information must be manually re-entered or "fat-fingered" into multiple systems. Stove-piping of systems is likely to result in data-entry errors and time delays in analyzing and disseminating intelligence. In a coalition context, the number of different systems is likely even greater, further exacerbating this problem.

V. Conclusion

We applied approaches from Human Factors to identify gaps in ISR and provided recommendations for technology. The wide range of the gaps indicates the scope of the challenges for implementing technology.

This paper has strengths and weaknesses. The strengths are identifying gaps from the Soldier perspective, rather than only a technological one, and a relatively large number of subject matter experts compared to similar research. A weakness is the use of self-report, qualitative data from interviews. Stronger empirical inferences can be made from other research methods, such as observational data and objective, quantitative data (e.g., [35]). Another weakness is the focus on breadth over depth. This is a general limitation of analysis at the more abstract, functional or activity, level compared to the specific lower level of tasks and cognitive task performance. Given the unpredictability and adaptability of Soldier activities in ISR, combined with its high dimensionality (system interactions), we assert that a broad understanding of problems is an informative starting point. Our work has high breadth, identifying general gaps in ISR, but limited detail for gaps.

Technology has enormous potential to enhance the effectiveness in ISR, but for technology to be effective it must provide solutions to actual Soldier needs. In future work, we plan to research human decision-making for ISR allocation

[3] http://www.palantir.com/solutions/intelligence/

[4] http://www.opengeospatial.org/domain/swe

[5] http://www.terraharvest.net/

with and without decision-aids using SAM. Results from future work may help iteratively refine the capabilities of technical systems, enhancing human performance.

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